JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
312/99.DTL-1
January 20, 1999

TO: **Ralph Roncoli**

FROM: **Dan Lyons** 264-214 x 31004

SUBJECT: **Preliminary Mars Planetary Constants and Models for Mars Sample Return**

REFERENCES:

1. "The JPL Mars Gravity Field, Mars50c, Based Upon Viking and Mariner 9 Doppler Tracking Data", Alex Konopliv and William Sjogren, Feb. 1995. JPL 95-5.

2. Mars Pathfinder Project, "Planetary Constants and Models", Robin Vaughan, Dec. 1995, JPL D-12947

3. "The Mars Global Reference Atmosphere Model, (MarsGRAM)", C.G. Justus and G. Chimonas, Georgia Tech Project G-35-685, Prepared for NASA Marshall Spaceflight Center under Grant No. NAG8-078, July, 1989.

4. "JPL Planetary and Lunar Ephemerides, DE405/LE405", E. M. Standish, IOM 312.F-98-048, Aug. 26, 1998 (http://ssd.jpl.nasa.gov/iau-comm4/de405iom/)

5. "Update to Mars Coordinate Frame Definitions", Robert A. Mase, IOM 312.B/001, Jan. 1999

6. "Report of the IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 1994", M.E. Davies, et al., Celestial Mechanics and Dynamical Astronomy 63: 127-148. 1996.

INTRODUCTION:

The following is a preliminary summary of the Planetary Constants and Models that are recommended for use by the Mars Sample Return analysis and design.

DISCUSSION:

Mars Gravity Field:

The official gravity field for Mars Sample Return is Mars50c, which is described in Reference 1. Truncating the field will usually be acceptable for preliminary design. The gravity field is available in both normalized and unnormalized forms, and the user is cautioned to check to be sure the appropriate values are being used.

Common Planetary Constants from either the Mars Pathfinder Planetary Constants Document (Reference 2), Mars50c (Reference 1), or the IAU (Reference 6):

Mars:

1 Sol	= 88775.245 seconds	(A Mean Solar Day on Mars)
$R_{Atmo\text{-}Interface}$	= 3522.2 km	(Radius at "Atmospheric Interface")
$R_{Ref\text{-}Mars50c}$	= 3394.2 km	(Reference Radius of Mars Used by Mars50c)
GM_{mars}	= 42828.370371 km^3/sec^2	(Gravitation Parameter from Mars50c) (Gm_{mars} = Gravitational Constant • Mass of Mars)
GM_{phobos}	= 7.090 E-4 km^3/sec^2	(Gravitation Parameter from Mars50c)
GM_{deimos}	= 1.589 E-4 km^3/sec^2	(Gravitation Parameter from Mars50c)
$R_{IAU\text{-}MarsPole}$	= 3375.8 km	(Radius of Mars Pole, IAU)
$R_{IAU\text{-}Equator}$	= 3393.4 km	(Mean Radius of Mars Equator, IAU)
α_{mars}	= 317.681° - 0.108 T	(IAU Right Ascension of Mean Mars Pole in EME2000)
δ_{mars}	= 52.886° - 0.061 T	(IAU Declination of Mean Mars Pole in EME2000)
T	= D / 36525	(Centuries Past Epoch of 2000. (IAU))
D	= (JulianDate - J2000)	(Days Past Epoch of 2000. (IAU))
J2000	= 2451545.0	(Reference Julian Epoch of 2000: Julian Days)
W_{mars}	= 176.901° + 350.891983 D	(deg. Prime Meridian w.r.t. "Node Q" of date)

Reference 6 defines "Node Q" for Mars as Right Ascension = (α_{mars} + 90°), Declination = 0, which is the intersection of the Mean Earth Equator of J2000 and the Mean Mars Equator of Date in the direction of the cross product of the Mean Earth Pole of J2000 ($Z_{EME2000}$) and the Mean Mars Pole of Date (Specified by α_{mars}, δ_{mars}). W is measured from Node Q along the Mars Equator of Date to the intersection of the Prime Meridian with the Mars Equator of Date.

Earth:

GM_{earth}	= 398600.4329 km^3/sec^2	(Gravitation Parameter from DE405)
$R_{Earth\text{-}Pole}$	= 6356.75 km	(Radius of Earth Pole, IAU)
$R_{Earth\text{-}Equator}$	= 6378.14 km	(Radius of Earth Equator, IAU)
α_{earth}	= 0° - 0.641 T	(Right Ascension of Mars Pole in EME2000)
δ_{earth}	= 90° - 0.557 T	(Declination of Mars Pole in EME2000)
W_{earth}	= 190.16° + 360.9856235 D	(Prime Meridian w.r.t. "Node Q for Earth")

Reference 6 defines Node Q of date for Earth as Right Ascension = (α_{earth} + 90°), Declination = 0. Therefore Node Q is very close to $Y_{EME2000}$. W is measured from Node Q along the Earth Equator of Date to the intersection of the Prime Meridian with the Earth Equator of Date.

Miscellaneous:

GM_{sun}	= 132,712,440,017.9870 km^3/sec^2	(GM of SUN from DE405)
c	= 299,792.458 km/sec	(Speed of Light)
AU	= 149,597,870.691 km	(Astronomical Unit)
$F_{1\ AU}$	= 1358 W/m^2	(Solar Radiation Flux at 1 AU)
ΔT	= ET - UTC	(≈ 64.184 sec As of January 1, 1999)
ET	Ephemeris Time	(Used in all JPL Mission Analysis Software)
UTC	Universal Coordinated Time	(Maintained by Ground Based Observatories)

Mission Analysis conversions to UTC will be based on the current value of ΔT at the time of the conversion, which will be listed to avoid confusion later when the value o ΔT changes.

Reference Coordinate System:

The fundamental inertial reference coordinate system will be Earth Mean Equator of J2000 (EME2000), which is referenced to the FK5 star catalog such that:

$Z_{EME2000}$ = Mean North Pole of the Earth on Reference Epoch of J2000

$X_{EME2000}$ = Parallel to Vernal Equinox of Earth Mean Orbit on Epoch of J2000

$Y_{EME2000}$ = Completes the Right hand system.

See Reference 5 for a complete discussion of the various coordinate frames.

The Mars Surveyor Operations Project Spacecraft Team at Lockheed Martin Astronautics in Denver uses a "Mars Mean Equatorial" (MME) system that is related to the standard inertial EME2000 system by the following transformation from a vector expressed in EME2000 $\{V_{EME2000}\}$ to the same vector expressed in MME $\{V_{MME}\}$:

$$\{V_{MME}\} = \begin{bmatrix} 0.67325770 & 0.73940790 & 0.0 \\ -0.58963084 & 0.53688030 & 0.60340290 \\ 0.44616082 & -0.40624560 & 0.79743651 \end{bmatrix} \{V_{EME2000}\}$$

This system is identical to the IAU Mars centered intertial coordinate system of J2000 described in Reference 5 (pg.12).

Mars Atmosphere:

MarsGRAM is computer software that will be used to provide Martian atmospheric properties for analysis and design. Reference 3 describes the original MarsGRAM model. MarsGRAM has been updated several times since the original release, where the updates are described in the version history file that comes with MarsGRAM. The MarGRAM software returns an estimate of the density, temperature, pressure, scale height, and other quantities for input values of date, latitude, longitude, altitude and other parameters, including dust loading. The latest release is MarsGRAM 3.7. MarsGRAM can be obtained by contacting Jere Justus at (256) 544-3260 or by emailing a request describing the intended use to Bonnie.James@msfc.nasa.gov.

Caution: MarsGRAM calculates altitudes based on its own surface reference ellipsoid, which has the following radius values.

$R_{marsgram}XY$ = 3393.94 km = Sqrt(3394.67 * 3393.21) Equatorial Radius

$R_{marsgram}Z$ = 3376.78 km Polar Radius

Further information about MarsGRAM can be obtained on-line through the NASA technical information center at

http://www.nasa.gov/techinfo.html (click on Technical Reports)

Search for "TM AND 108513" and "TM AND 108509"

Ephemerides:

The recommended planetary ephemeris, DE-405, described in Reference 4 can be obtained internally at JPL from:

/afs/jpl.nasa.gov/group/sec312/data/unix/ephem/de405s.nio

A CD-ROM containing the planetary ephemeris can be purchased for about $25. from:

Willmann-Bell, Inc
PO Box 35025
Richmond, VA 23235

(804) 320-7016 or FAX (804) 272-5920

http://www.willbell.com/software/jpl.htm

The recommended Martian satellite ephemeris, mar033.7.nio, can be obtained via anonymous ftp from:

ssd.jpl.nasa.gov/pub/eph/satellites

The postscript file readme.ps describes all of the files, the *.doc files are text files containing the delivery forms, the *.nio files are navioephemeris files, and the *.xsp files are the export SPK files.

Time Systems:

The two primary timekeeping systems are Universal Coordinated Time (UTC) and Ephemeris Time (ET). Both systems count the number of “System Internationale” (SI) seconds from a reference epoch. The SI second is defined by the oscillation of an undisturbed cesium atom, and is sometimes referred to as “atomic time”.

Ephemeris Time (ET) is the independent time variable used in the equations of motion of bodies in the solar system. ET is used by the Navigation section as the reference time for propagating orbits, using planetary ephemerides, etc. ET is related to atomic time, Temps Atomique International (TAI), as measured by the International Earth Rotation Service in Paris, France by

ET = TAI + 32.184 sec $\pm$ 0.002 sec (the variability is due to relativistic effects).

Univeral Coordinated Time (UTC) is a time system based on the SI second, and is adjusted periodically by adding leap seconds in order to keep “Midnight” at 0 hours as measured at the Royal Observatory in Greenwich, England. UTC is an atomic time that is available on the Earth. On January 1, 1999, the difference between ET and UTC became

$$\Delta T = ET - UTC = 64.184 \text{ sec}$$

By the time the Mars Sample Return mission is flown, ΔT will probably have increased by several seconds. The official source for ΔT can be found at the United States Naval Observatory web site:

http://tycho.usno.navy.mil/time.html

or at http://hpiers.obspm.fr/